1917

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Engineering and Mining Journal

VOLUME 103 FEBRUARY 24, 1917 NUMBER 8

New Developments in the Porco District, Bolivia

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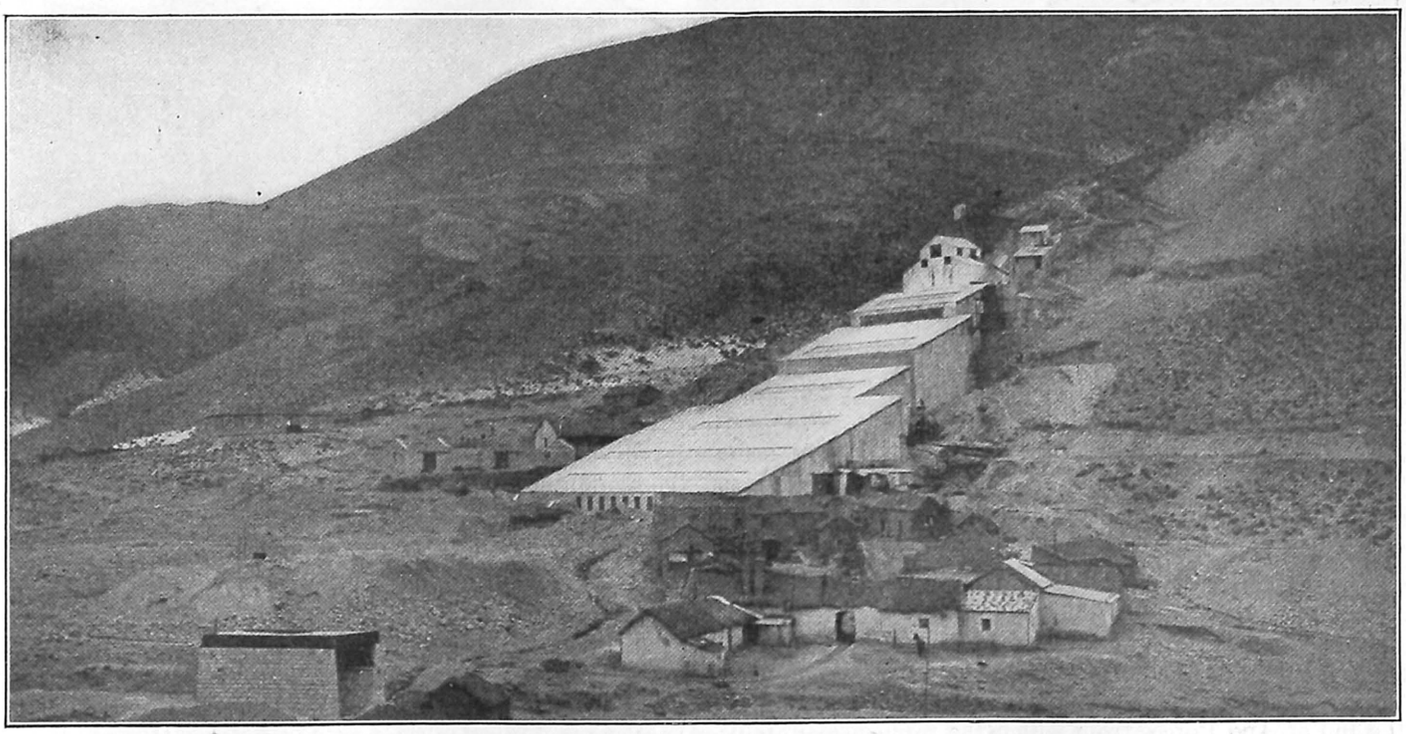
SYNOPSIS—The Porco mines were among the first to be worked in Bolivia for silver and are now being worked for tin, the silver-bearing high-grade veins having been worked out. At present operations are conducted by the Porco Tin Mines, Ltd., on wide-vein low-grade oxidized tin ores. Concentration in a 120-ton mill is practiced and barilla shipped.

The Porco mines are said to be the first in Bolivia worked by the Spaniards, and the neighboring but more famous district of Potosi was discovered in 1544 by a miner from Porco. Like Potosi, it was originally a silver camp of considerable importance, but the rich silver ores were soon exhausted and there came a long period during which the mines were practically abandoned; hence, when in later years mining was resumed, titles were taken according to the Bolivian law and the old *boca mina* law, still in force at Potosi, no longer exists here. In recent years tin mining had been conducted in a more or less desultory way by Bolivians who had a mill for treating the ores at Agua Castilla, which extracted both silver and tin. These operations have now been superseded by those of the Porco Tin Mines, Ltd., which company acquired the properties in 1912.

The chief mineralized area is confined to a mountain mass culminating in a peak of about 17,000 ft. elevation called Apo Porco and having as one of its spurs a smaller and lower peak known for that reason as Huayna Porco. Both of these peaks are mineralized but, as will be described farther on, in a different manner. The town of Porco is a small Indian village lying near the mouth of a gulch at the foot of the mountain on the opposite side of Huayna side of Huayna Porco from the mines. It is a most primitive and picturesque place, consisting entirely of crude houses built of boulders collected from the stream and hill slopes and covered with thatched roofs. In many of them the inhabitants have not even taken the trouble to fill the crevices between the stones with mud, so that the house affords only



THE AGUA CASTILLA MILL IN THE PORCO DISTRICT, BOLIVIA

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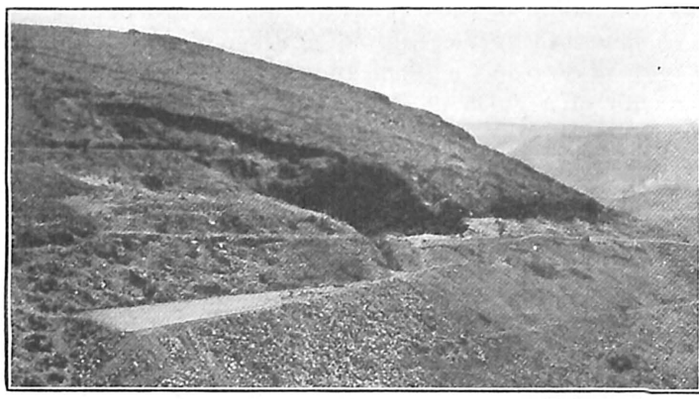
partial protection against wind and cold. The railroad from Rio Mulato to Potosi that was opened in 1912 passes only 5 km. from the mines and the town, the station for both of which is Agua Castilla, 114 km. from Rio Mulato and 60 km. from Potosi, and the only station on the entire line. These improved transportation facilities made the development of the Porco ore deposits along the lines of a low-grade, large-scale proposition possible and resulted at once in the application of foreign capital to that end. It is believed that the Porco Tin Mines, Ltd., is closely affiliated with the Aramayo Francke Co., Ltd., interests.

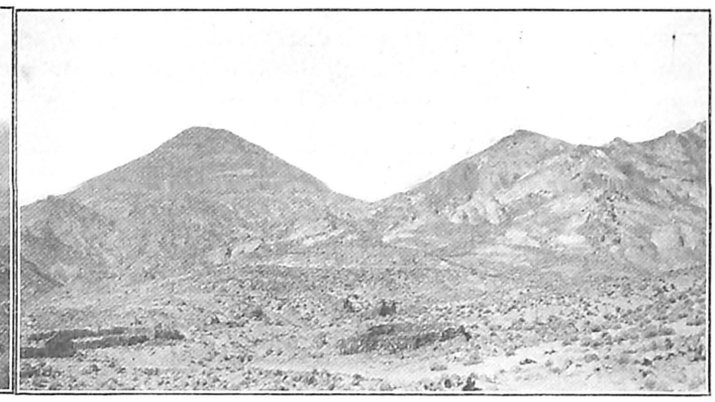
The impression one receives of the geology of the country in traversing it on the railroad is rather erroneous. The train leaves Rio Mulato every Saturday morning at 8:25. For a short distance the road traverses the *altiplanicie,* skirting several knolls of igneous rock that rise above it, and then enters the Cordillera Real for the rest of the journey. The train climbs continuously until about one o'clock, when the highest point on the line is reached at an elevation of 15,814 ft., more than 3000 ft. above Rio Mulato and the highest point on any Bolivian railroad. From here there is a rapid descent of over 2000 ft. to Agua Castilla, reached about an hour later. The rock seen along the entire route consists of light-colored volcanics carrying abundant biotite and quartz phenocrysts, and apparently rhyolitic in composition.

The ridge at the foot of which the Agua Castilla mill is situated is capped by an igneous flow that manifests considerable difference in appearance from place to place, but which in general is characterized by an abundance of biotite, a varying amount of quartz, and feldspar phenocrysts that are chiefly orthoclastic, and consequently seems to range in composition from rhyolite to trachyte. Underlying this flow is a heavy, distinctly cross-bedded sandstone, the one previously mentioned, which readily disintegrates and has yielded a large amount of sand that has accumulated in the form of dunes in the direction of Porco. Beneath the sandstone on the road from the mill to the mines are several small exposures of a dark gray to black shale. On the northeast, east and south sides of Apo Porco, the igneous rocks of that mountain are in contact with a very heavy quartzite, in which the bedding is not very distinct, but which, in so far as it can be recognized, is that of a heavy, cross-bedded sandstone. As no other quartzite of this character was seen in the region, it seems probable that it represents a local metamorphosed phase of the friable sandstone previously mentioned.

The two mountains, Apo Porco and Huayna Porco, are composed entirely of igneous material. Their lower parts are composed of quartz porphyry, rhyolitic tuff and agglomerate. The agglomerate in particular is characterized by an abundance of shale fragments, and



OPENCUT ON THE SAN JOSÉ VEIN



APO PORCO AND HUAYNA PORCO

Some phases of the rocks represent compact porphyries, others are more pumaceous in texture. A short distance before reaching Agua Castilla, in the walls of a deep gorge on the south side of the track, we saw some excellent examples of columnar structure in the volcanics. Just beyond Agua Castilla, on the way to Potosi, for a short distance an area of tan-colored, heavy, cross-bedded sandstone is passed through, after which only igneous rocks are again encountered until near Potosi. The impression gained from the railroad is that of a vast area of prevailingly igneous rock. Quite the reverse are the true relations unfolded by the magnificent view from the top of Apo Porco, from which the famous mountains of Potosi, Tasna and Chorolque are visible. The country that spreads out for miles before one is seen to consist for the most part of sedimentary rocks, the bedding of which is distinctly visible on the almost barren hills. Here and there are igneous intrusions and cappings of lava, some of considerable areal extent, but the whole constituting a minor part of the terrain. It is mere chance, therefore, that the railroad throughout nearly its whole extent traverses igneous rocks.

only a few sandstone or quartzite fragments were noted, indicating that the underlying rock consists of the dark shales, chiefly Paleozoic in age, that constitute such a large part of the eastern range of the Andes in Bolivia. The summit of Apo Porco appears to be entirely devoid of mineralization and consists of a quartz trachyte with large feldspar phenocrysts, some of them as much as 2 in. long, and is almost devoid of foreign inclusions.

The chief mineralization has taken place within a very restricted area that includes Huayna Porco and the adjoining portions of Apo Porco; especially that portion on the east side of Huayna Porco. By far the greater part of the mining in the past was done on Huayna Porco, which in places is almost as completely covered with old mine dumps as is Potosi Mountain. The reason for this is that the veins are argentiferous and in colonial days yielded rich silver ores. They are usually narrow, run in fairly straight lines and carry an ore consisting of high-grade argentiferous galena, sphalerite which is usually low in silver, and here and there pockets of ruby silver. The richest parts of these veins have long since been worked out, and they are today abandoned.

In contrast to the veins of Huayna Porco, those of Apo Porco are wide, carry but little silver and galena, in the sulphide zone contain mostly pyrite and in places considerable sphalerite, and are characterized by their tin content, which exceeds in value the silver. Mining in recent years has been confined to these ores. Most of the work has been done in the oxidized ores that are said to average 12 oz. silver and 2½% tin. The sulphide ores average much lower in tin, indicating a tin enrichment in the oxidized zone. No cassiterite was recognized in the sulphide ore, showing that it occurs in small particles in the primary ore. The same is true to a large extent of the oxidized ore, and where it is visible it occurs as minute black specks either in the soft clayey material of the gossan or as a thin coating on the surface of rock fragments. Very little *guia,* as the high-grade cassiterite that can be hand-sorted is called, is encountered anywhere in the veins. This manner of occurrence of the cassiterite makes it likely that the tin enrichment in the oxidized ore is to a large extent both residual and mechanical. The elimination of the sulphides of the primary ore would of itself cause a considerable relative enrichment in tin. The small particles of cassiterite liberated in the then porous oxidized material doubtless to some extent sift down through it and in this way add to that originally present, causing an actual increase in the amount of tin in the oxidized parts of the veins. Harold A. Lewis, manager of the mines, is also inclined to believe that concentration may have taken place in this way, and told us of another instance to which he gave the same interpretation. In the Berenguela district, Mr. Lewis said, the highest tin content is encountered in the sulphides under the oxidized ores. These sulphides are very porous and drusy, and the openings are filled with small particles of cassiterite which he believes is due to a mechanical downward migration. At Porco the migration was confined to the oxidized zone. It is quite possible that in the presence of the sulphuric acid and ferric sulphate generated in the oxidation of the pyrite, there may have been some solution and redeposition of the tin. This action is generally believed to take place to a limited extent in tin ores, however, so that the first explanation appears the more plausible.

Many Antimony Bearing Veins Occur

In addition to the mineralization of the Porco Mountains, there are a great many antimony veins in the shales of the surrounding country that were actively exploited during the recent high prices for that ore, and Agua Castilla was one of the principal shipping points of the Bolivian production during that period. Though the veins are comparatively narrow in most instances, the filling consists chiefly of stibnite, with only subordinate quantities of quartz, which is the most abundant gangue mineral, so that it is easy to secure hand-sorted stibnite with which is often associated a little antimony ocher carrying 50 to 55% antimony. The mines are small, crudely worked properties, generally operated by Indians. The latter prospect the mountains and, on locating a promising vein, bring samples to someone capable of financing the project and in return for permitting him to denounce the claims are given the privilege of working them and are paid by the quintal for the ore when delivered at the railroad. Many antimony-mine owners have never seen their mines. This procedure is due to the fact that the Indians lacking capital are forced to realize on their labor at once; whereas the owner of the property receives, as his compensation for advancing the money and waiting several months for settlements the wide margin between the price received by the Indians and the market price of the metal, which may be as much as 50%.

Mining Operations Conducted by Porco Tin Mines, Ltd.

The Porco Tin Mines, Ltd., is the only operator in the district, and its property includes the whole of the mineralized area of Apo Porco and a large part of Huayna Porco, but it is mining only the tin veins of Apo Porco. The mine offices are situated in the ravine between the two mountains on the north side of Apo Porco at the tunnel of the old Pie de Gallo mine, which was the most important of the silver mines on Huayna Porco. A short distance above the buildings is the tram terminal from which the ore is sent to the mill. Here the Dolores adit, the principal adit of the company crosscuts 800 to 900 ft. south to the principal vein, the San José. The vein on this level consists of heavy pyrite and carries only a fraction of a per cent. of tin and about 8 oz. silver. The country rock is agglomerate, tuff and quartz porphyry. Besides fragments of igneous material, the agglomerate and to a less extent the tuff are characterized by an abundance of shale fragments. A raise from this level serves as an ore course from the main San José level.

The San José adit enters the hill farther to the east and 72 m. higher than the Dolores. It is a 400-ft. crosscut to the west to the San José vein, which has been drifted on from it to the north and to the south. The Dolores connection is made in the north drift, and at the same point is a raise to the surface to connect with a surface tram that brings the ore from the Santa Rosa and Misericordia veins. The plan of mining the San José vein above this level is to glory-hole the outcrop and a series of raises 30 m. apart and extending to the surface that are to serve as ore chutes were about completed at the time of our visit. This level as far as developed is in the oxidized zone, though occasional patches of sulphides are encountered; but at the breast of the south drift the vein consists of small stringers of sulphide, chiefly pyrite, cutting a country rock very much impregnated with pyrite, indicating that the sulphide zone has been reached. A level 22 m. below the San José is practically at the contact of the oxidized and sulphide ores. The country rock of these workings is similar to that in the Dolores level, except toward the north end, where there is a very dark agglomeratic rock that looks as if it might be a dark mud flow that gathered up the included rock fragments.

The San José oreshoot developed in these workings has a length of about 150 m. and an average width of 2 m. The maximum width is near the south end of the outcrop, where a width of 20 m. is being removed for a short distance. The vein has a strike of N 10-20° E and a dip that changes from nearly vertical at the north end to much flatter southeasterly at the opposite end. It is not a simple fissure filling, but a lode fissure or shattered zone. In the sulphide zone, the veinlets are more or less distinct, though the intervening rock is impregnated with pyrite. In the oxidized zone, the pyrite has completely changed to limonite and the

adjacent country rock is thoroughly altered and iron-stained, so that the entire width of the lode fissure consists of the highly ferruginous, low-grade stanniferous, soft material that constitutes the great bulk of the ore. Some of it is of very smooth, uniform texture like kaolin and is stained a light to reddish yellow. Though usually soft, this material is in places silicified and hard. The San José dump will also be sorted, since it is found to yield a 2% ore that can be profitably milled.

A short distance south of the San José workings, a second oreshoot on the same vein is opened up by the Zuñiga level. This shoot is 30 to 50 m. long, averages 2½ m. wide and the ores run 3% tin. The importance of the San José vein is indicated from the fact that 80% of the developed ore of the company is in this vein.

Two other veins east of the San José and parallel to it in strike but with a steep westerly dip—that is, toward the San José—the Misericordia and Santa Rosa, are being developed. The Santa Rosa mine has an adit 400 ft. long, penetrating the hill in a southerly direction, and as the hill rises in this direction, the adit first passes through oxidized ores and then into the sulphide zone. The sulphide ores consist chiefly of pyrite, but contain also considerable sphalerite. The oxidized ores are of the same character as those of the San José. The vein averages about 0.7 m. in width. A surface tram connects the adit with the ore chute from the surface to the San José level of the San José mine, the difference in elevation of the two levels being 42 m.

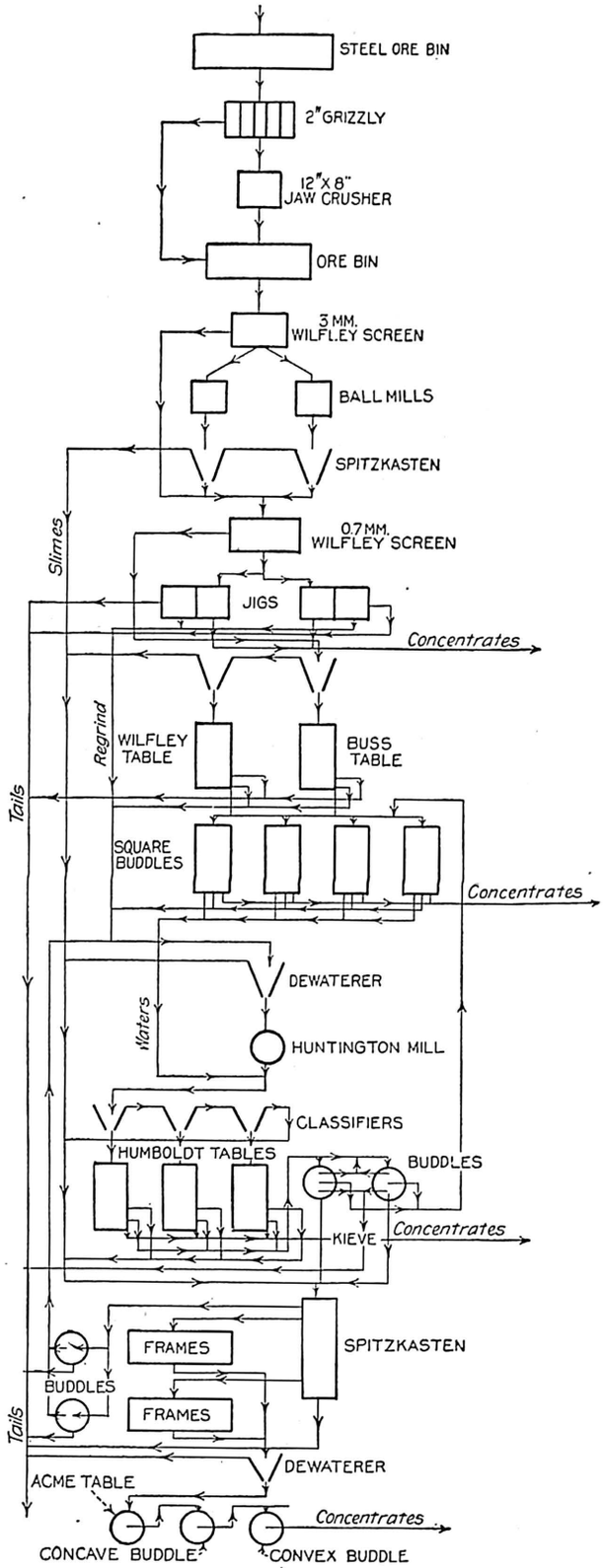
The Misericordia vein lies between the Santa Rosa and the San José, about 50 m. from the former. It is developed by an adit 45 m. higher than the Santa Rosa in the oxidized ores and a crosscut from the latter, which penetrates the sulphide zone, with a raise to the adit to serve as an ore course. The Misericordia is a fissure vein of less than 1 m. in average width and filling consisting chiefly of sphalerite, in places almost pure coarsely crystallized dark zinc blende, mingled with more or less pyrite and locally a little galena. One face of such ore showed 3% tin, but in general the tin content of the sulphides is much lower. The oxidized material differs from that of the other two veins in being of distinctly red instead of yellowish color and is said to run higher in tin. In addition to the three principal veins described, there are a number of others on the property.

Milling at the Agua Castilla Mill

The mine workings are all connected in such a way that the ore is brought through the Dolores adit to the aërial tram terminal close to its portal. The tram is of the single-cable type 4200 m. long, the longest span of which is 1082 m. Since the mill terminal is only 240 m. below the mine terminal, which has an elevation of 13,400 ft., and there is an intervening ridge 220 m. higher than the latter gravity does not suffice to operate the tram and must be supplemented by a 15-hp. motor. The buckets have a capacity of 400 lb. The cost of the tram was £8000. At the mill are an automatic counter and scales.

The mill is situated 1 km. east of Agua Castilla station on the north side of the railroad, from which it is served by a siding, and was completed in June, 1915, at a cost of £25,000. It is run by water power furnished by a 222-m. head. A small reservoir in the ravine back of the mill, supplying the flume, is fed by a spring called Agua Castilla on account of the clearness of its water, which furnishes a flow of 3½ in. over a 3-ft. weir from a point 60 m. higher up.

The mill is constructed in two similar units, only one of which will be described. On arriving at the mill, the ore is dumped into a 60-ton steel bin, from which it is



FLOW SHEET OF ONE SECTION OF AGUA CASTILLA MILL

run over a 2-in. grizzly and the oversize after removing the larger masses of barren rock fed to a 12x8-in. jaw crusher. The entire product goes to a second bin, which feeds a 3-mm. Wilfley shaking screen the oversize of which is ground in two ball mills and the undersize passes to a second Wilfley screen of 0.7 mm. mesh. The ball mills

are equipped with 1-mm. screens, and the pulp from each is classified in a spitzkasten. The overflow goes to the slimes launder and the settlings to the second screen.

The screen oversize is distributed by a launder classifier to two 2-compartment Harz jigs. The feed of the coarse jig is considerably higher in tin than the unclassified material, a 2½% ore giving a coarse feed with 5% tin. The screens of the first and second compartments of the coarse jig are 2 mm. and 3 mm. respectively and of the second jig 1.7 mm. and 2 mm., and pyrite is used for the bedding. Concentrates with 55% tin, middlings that are reground in a Huntington mill and tailings that go to the creek are produced by the jigs. The screen undersize goes to a pyramidal dewaterer, the settlings of which are treated on a Buss table and the overflow in a second dewaterer, the settlings in turn being treated on a Wilfley table and the overflow going to the slimes launder. The tables yield a 35% concentrate which is rewashed by hand on four square buddles, the tails from which are reground and the waters added to the regrind pulp, middlings that are dewatered and reground and the waters passed to the slimes launder, and tailings carrying 0.3% tin which go to the creek.

The Huntington mill has a 0.7-mm. screen, and its pulp flows through a series of three pyramidal settlers for classification, each of which feeds a Humboldt table, and the overflow the slimes launder. These tables make a concentrate that is re-treated in a kieve, waters that go to the slimes launder and an intermediate product that goes to two buddles with revolving arms. The heads from these buddles are re-treated on the square buddles, the middlings in the same buddles, the tailings go to the creek, and the overflow to the slimes launder.

The slimes launder empties into a long spitzkasten at the bottom of the upper end of which is a spigot to catch any sands the slimes may contain. Such sands are treated on two buddles to the left of the frames which yield heads carrying 1 to 2% tin that go to the regrind, the tailings and overflow being discarded. The spitzkasten also has two spigots for slime settlings, each of which feeds a row of 10 frames. The overflow from it goes to the creek. The concentrates from the frames go to a settling tank the overflow of which is also discarded and the settlings sent to an Acme table. The concentrate of this table is further treated in a concave buddle and that of the concave buddle of each unit of the mill in a single convex buddle.

Plant Exceeds Designed Capacity

The mill was originally designed to treat 80 tons of ore daily, but the one unit in operation at the time of our visit was handling 50 tons and could take care of 60 tons, so that the plant really has a capacity of 120 tons. The mill feed averages 12 oz. silver and 2½% tin. Operations had not been under way long enough to get the mill in complete adjustment so that it was not known what tin recovery could be made. The tailings carry 10 oz. silver showing that there has been but little or no concentration of it. Cyanidation of the tailings to recover the silver is being considered.

In addition to the equipment described, there is a roasting furnace and drier. It is found that the pyrite in the ore goes mainly into the fine-grained *barilla,* or concentrates, which carries less tin consequently than the coarse. The second layer in the kieve contains much pyrite and will be roasted. There is some barite in the *barilla,* and this mineral has been seen in small amount in the Misericordia ore. No antimony minerals have been recognized, but occasionally there is a little galena.

The mill is one of the most modern and best constructed in Bolivia, and the results of this attempt at mining low-grade tin ore in that country will be awaited with much interest and will doubtless exert a considerable influence on the development of the tin-mining industry of Bolivia.